Testing Components of a New Community Isopycnal Ocean Circulation Model

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Modelling

The ocean and atmosphere are both governed by the same physical laws and models of the two media have many similarities. However, there are critical differences that call for special methods to provide the best simulation. One of the most important difference is that the ocean is nearly opaque to radiation in the visible and infra-red part of the spectrum. For this reason water mass properties in the ocean are conserved along trajectories for long distances and for long periods of time. For this reason isopycnal coordinate models would seem to have a distinct advantage in simulating ocean circulation. In such a model the coordinate surfaces are aligned with the natural paths of near adiabatic, density conserving flow in the main thermocline. The difficulty with this approach is at the upper and lower boundaries of the ocean, which in general do not coincide with density surfaces. For this reason hybrid coordinate models were proposed by Bleck and Boudra (1981) in which Cartesian coordinates were used near the ocean surface and isopycnal coordinates were used in the main thermocline. This feature is now part of the HICOM model (Bleck, 2002).

The original goal of this project was to develop modules for the upper boundary layer of an isopycnal model that would be “plug compatible”. In other words subroutines would be written that could be used in various isopycnal models to represent the surface mixed layer and the upper thermocline. The advantage of such modules would be to allow a comparison of two isopycnal models with slightly different architectures, but with exactly the same formulation of the upper boundary layer, which plays a critical role in governing the flow of heat and water into the ocean. Unfortunately this seemingly attractive goal turned out to be naive. Modern ocean models are designed to be integrated on massively parallel computers, in which the computation is split between many individual processors, in some cases more than one thousand. With the use of these machines the cost of computing has been drastically reduced and it is possible to carry out calculations that were entirely unfeasible only a decade ago. However, this advance has come at the cost of complexity in the coding. Elaborate protocols are required to manage the parallel computation that were unnecessary when serial calculation were the norm. Generally the exact protocols differ from one modeling group to another. Thus our experience in trying to design general subroutines that could inserted in different ocean models programmed in different laboratories is impractical.

This conclusion was reached in trying to convert the Hallberg HIM model at the GFDL/NOAA in Princeton to a hybrid model with a KPP (Large et al, 1994) formulation for vertical mixing. The model was set up for a simulation of the World Ocean using a horizontal resolution of approximately of degree of latitude by one degree of longitude. The upper boundary conditions specify the seasonally varying flux of heat, momentum and water at the ocean surface (Large and Yeager, 2004). The Large and Yeager (2004) boundary conditions are excellent for testing a new model, since the results of other modeling groups are available for comparison.

The isopycnal Hallberg-HIM model was modified to include:

1. A fixed vertical grid from the surface to 200 m with 10 m intervals with isopycnal coordinates below.
2. A subroutine to calculate the KPP mixing coefficients for tracers and momentum.
3. Calculate the diffusion of tracers on the tracer time step and the mixing of momentum on the velocity time step.
4. Apply convective adjustment to guarantee vertical stability.
5. Apply an interpolation procedure to remap tracers and momentum from the moving semi Lagrangian, vertical grid to the fixed grid in the upper ocean at every tracer time-step.

The KPP routines were modified from the Los Alamos POP code to allow for the hybrid vertical coordinates. Due to the different programming protocols many technical difficulties were encountered. Test runs were successfully carried out for 4 years duration. Comparing the SST simulation with observations the model was able to produce patterns in agreement with observations, except for a strong cold bias in the Equatorial Pacific. Analysis suggests that this was due to errors in the mixing of tracers and an omission of the remapping of momentum at each time step, which has been corrected and new tests are being carried out. In an independent effort the ocean modeling group at GFDL have formulated another hybrid version of HIM with a more elaborate version of vertical remapping. This should be ready for testing in a realistic framework by the end of this year.

Other Studies

Two other studies have been undertaken by the PI in collaboration with others. Cessi et al, (2004) examined the possible interaction of Atlantic and the Pacific through the wave signal in the ocean. This study was motivated by the question of a link between Atlantic and Pacific climate on the multidecadal time scale of the AMO. The response of a density perturbation applied to the North Atlantic along a path to the South Atlantic and out into the Southern Ocean was calculated in a three dimensional ocean circulation model and in a simplified, linear, shallow water model, calibrated to correspond to the first baroclinic mode of the World Ocean. Within the Atlantic the three dimensional model and the simplified linear model were in general agreement, but in the Southern Ocean the signal took markedly different paths. In the shallow water model the signal hugged the east coast of Africa and propagated to the Equator, where it became an equatorially trapped Kelvin wave. In the more complete three-dimensional model the perturbation separated from the Cape of Good Hope and propagated directly eastward South of Australia and across the South Pacific eventually impinging on the west coast of South America. From there it moves northward and westward to the equator. The response of temperature and sea level in the Pacific sector was significant, but not large. Our results suggest that while the ocean connection between the Atlantic and Pacific may be important on very long time scales, other mechanisms, such as a direct teleconnection through the atmosphere are more important.

Another study by Williams and Bryan (2006) was motivated by the problem of sequestration of carbon dioxide in the deep ocean. The cooling of the ocean in the Late Glacial Maximum (LGM) could by itself lead to a lowering of atmospheric carbon dioxide as found in ice core measurements. However, an equator ward shift of the westerlies has also been proposed as an important factor in carbon dioxide take up by the Southern Ocean. There are now quite a few studies of LGM using coupled ocean atmosphere climate models. However an examination of the position of the Southern Hemisphere westerlies in these solution leads to ambiguous results, partly because most of these models have rather low horizontal resolution. Our study uses a rather detailed atmospheric model in simplified zonally symmetric geometry. Rather than use a coupled model the surface temperature is specified to correspond to the poleward surface temperature specified by proxy data. The atmospheric model contains a hydrologic cycle, and that turns out to be of crucial importance. For LGM temperatures tropical convection is greatly reduced and the Hadley cell contracts. This caused the entire wind system to shift toward the equator. Since the torque arm associated with angular momentum increases as on gets closer to the equator, and since the surface winds do not decrease in intensity, the westerly angular momentum extracted by the westerlies increases. A counter intuitive result is that the LGM easterlies have to increase in intensity to compensate.

Publications:

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